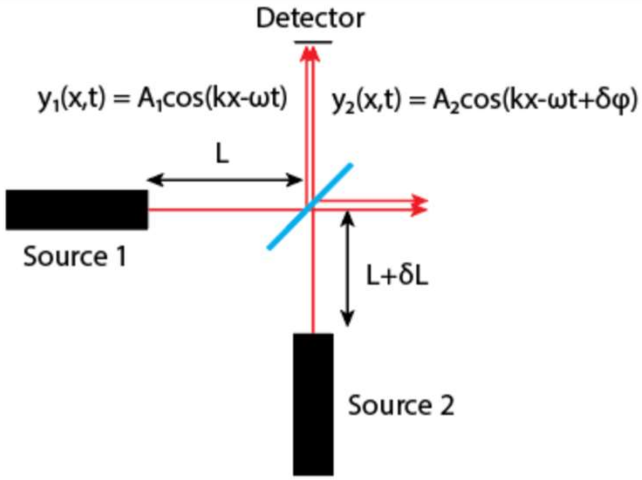
Lecture 20: Final review



Consider a version of the Michelson interferometer where two independent sources of the same frequency but different amplitude were combined on the beamsplitter, as shown in the figure. With both arms at length L and both sources in phase, the intensity is at a maximum. We then move source 2 by δL.

Important parameters are

- $\delta L =$ 52 nm
- $k =$ 0.021 nm^{-1},
- $A_1 = 2\sqrt{W/m}$
- $A_2 = 5\sqrt{W/m}$.

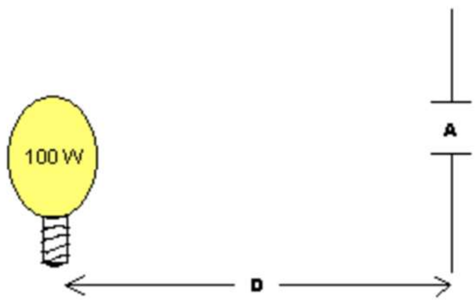
We adjust the phase of Source 2 to attain a maximum intensity again. What is the smallest positive phase offset $\delta\phi$ needed to ensure constructive interference on the detector?

A telescope focuses visible light of wavelength 400 nm from a distant star through a circular aperture to a diffraction-limited spot on a camera sensor.

Suppose that the angular width of the resulting diffraction spot is 0.001 radians. What is the diameter of the telescope aperture in milimeters?

- (a) 1.02e-12 mm
- (b) 2.44e-07 mm
- (c) 488. mm ✕
- (d) 0.976 mm
- (e) 0.000400 mm

✕ 0%



A 100 W incandescent light bulb converts approximately 2.5% of the electrical energy supplied to it into visible light. Assume that the average wavelength of the emitted light is $\lambda = 500$ nm, and that the light is radiated uniformily in all directions.

1) What is the energy of each photon in eV?
E =

2.48 eV

Submit Help

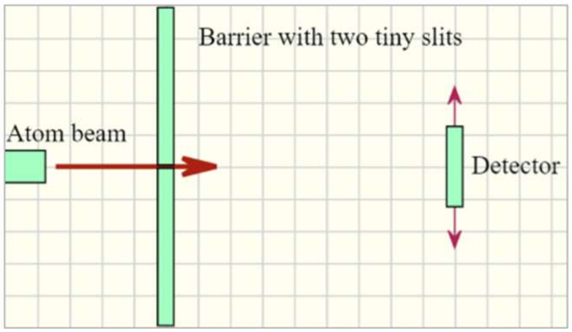
2) How many photons per second, N, would enter an aperture of area $A = 6\text{cm}^2$ located a distance D = 2 m from the light bulb?
N =

7.547*10^13 photons/s

Submit Help

Question 5: Estimating the mass of an atom

Suppose we have a beam composed of atoms of unknown mass, moving with a velocity 2.773 m/s. The beam of atoms is directed onto two slits separated by 13 μm. A detector is positioned 0.206 m away from the slits on a rail.



Part 1

As we move the detector down the rail, we find that many atoms hit it at position x=0, then as x increases fewer atoms hit it, until we finally find another maximum at x=0.791 mm. Using this, estimate the mass of the atoms.

- (a) 1.33e-26 kg
- (b) 1.80e-08 kg
- (c) 4.69 kg
- (d) 4.79e-27 kg
- (e) 2.39e-34 kg

Question 4: Electron Two-Slit Interference

A beam of electrons with velocity 5.00 m/s pass through **two slits** separated by 0.500 mm. We place a detector on a distant screen.

At which angle θ measured from the horizontal can we be sure that the probability of detecting an electron is as **small** as possible?

- (a) 0.621 rad
- (b) There is no minimum; the electron has equal probability to be detected anywhere.
- (c) 0.146 rad
- (d) 0.00 rad
- (e) 0.295 rad ✕

✕ 0%

An electron is in the ground state of an infinite square well. The lowest frequency photon that the electron can absorb is 7.50e+14 Hz.

What is the length of the well?

- (a) 0.348 nm
- (b) 0.364 nm
- (c) 0.492 nm
- (d) 0.603 nm ✓
- (e) 0.485 nm

✓ 100%

Which of the following gives the **second lowest** (next absorption energy after the first) photon frequency that can be absorbed by this electron (still assuming it starts in the ground state)?

- (a) 2.25e+15 Hz ✗
- (b) 2.50e+14 Hz
- (c) 1.25e+15 Hz
- (d) 1.00e+15 Hz
- (e) 2.00e+15 Hz

✗ 0%

Uncertainty

A particle is in the ground state of an infinite square well. What should we do to **increase** the spread of values we could find in a position measurement?

- (a) Measure the energy of the particle.
- (b) Decrease the mass of the particle.
- (c) Measure the momentum of the particle.
- (d) Decrease the length of the well.
- (e) Increase the mass of the particle.

Since p also equals m * v, why does decreasing mass not produce the same effect?

Question 3: Harmonic Oscillator 1

The longest wavelength of light that can be absorbed by a particular harmonic oscillator is λ = 700 nm.

What is the second longest wavelength that can be absorbed?

- (a) λ = 175 nm
- (b) λ = 350 nm
- (c) Every λ ≤ 700 nm can be absorbed.
- (d) λ = 490 nm
- (e) No wavelengths shorter than 700 nm can be absorbed. ✕

✕ 0%

Unit 5-8: quantum description of matter

a) Use the relationship of a particle's momentum and wavelength to compute the outcome of interference experiments.

b) Explain whether a wave function has definite momentum.

c) From a superposition of eigenstates, determine the probability of a measurement.

d) Apply the Heisenberg Uncertainty principle to determine the limits of what can be predicted about measurement outcomes.

Eigenstates

Which wave function has definite momentum?

$a)\ Ae^{ikx}$
$b)\ \mathrm{A}\cos(kx)$
$c)\ Ae^{-kx^2}$

What is the value of the momentum?

$a)\ \ k$
$b)\ \ hk$
$c)\ \ \hbar k$

Momentum and wavelength

An electron with velocity v is incident on a 2-slit experiment. What equation will give the angle of the first maximum in terms of the distance between the two slits b?

a) $\sin\theta = \frac{h}{bmv}$

b) $\sin\theta = \frac{bm}{hv}$

c) $\sin\theta = \frac{hv}{bm}$

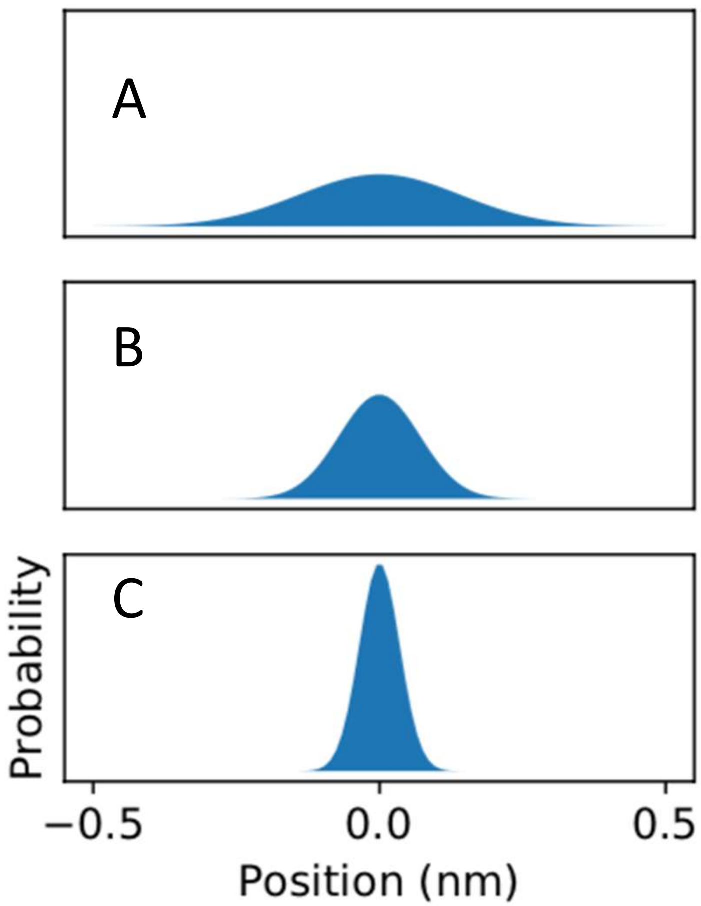
Superposition of eigenstates

Suppose that ψ_1 has definite position x_1 and ψ_2 has definite position x_2. Both are normalized.

If the wave function is $\mathrm{N}(5\psi_1 - 7i\psi_2)$, then what is the right probability of measuring x_2?

a) 1/2
$b)$ 7^2
$c)$ -7^2
$d)$ $\frac{7^2}{5^2+7^2}$
$e)$ $\frac{-7^2}{5^2+7^2}$

Heisenberg uncertainty



Probability densities on the left.

Suppose we measure momentum of this particle. Which will have the largest spread of possible momentum values?

Unit 8: time independent Schrödinger eqn

a) Check whether wave functions satisfy the time-independent S.E.

b) Relationship between wavelength, momentum, and energy for a free particle.

c) Compute energies for the infinite square well, and what photon energies can be absorbed/emitted.

Satisfying the time independent Schroedinger equation (twofer)

For a free particle, how can we satisfy the time independent S.E.?

$$\frac{-\hbar^2}{2m}\frac{\partial^2\Psi(x)}{\partial x^2} + U(x)\Psi(\mathrm{x}) = \mathrm{E}\Psi(x)$$

a) $\sin\frac{2\pi x}{L}$ for $0 < x < L$, 0 otherwise
b) Ae^{-kx}
c) Ae^{ikx}

Energies of the infinite square well

An electron is in an infinite square well. Starting in the ground state, the longest wavelength that it can absorb is λ. What is the length of the well L?

$a)\ \frac{hc}{\lambda} = \frac{4\hbar^2\pi^2}{2mL^2}$

b) $\frac{hc}{\lambda} = \frac{h^2}{8mL^2}(3^2 - 1^2)$

c) $\frac{hc}{\lambda} = \frac{\hbar^2\pi^2}{2mL^2}(2^2 - 1^2)$

Unit 9: Energy levels and harmonic oscillator

a) Use the allowed energies for a system to explain whether it is more likely that the system is described by a harmonic oscillator or infinite square well potential.

b) The levels of a harmonic oscillator are given by $\left(n + \frac{1}{2}\right)\hbar\omega$, with $\omega = \sqrt{\frac{k}{m}}$

Chemical bonds

Chemical bonds are well-described by harmonic oscillators. What is true about the photons that can be absorbed by a vibration in a material, assuming it starts in its ground state?

a) It can only absorb one frequency of light.
b) It can absorb frequencies of light that are $n\mathrm{C}$, with C a constant.
c) It can absorb frequencies of light that are n^2C, with C a constant.

Unit 10: Many electrons

a) Determine the ground state of a system of non-interacting electrons using energy level diagrams

b) Be able to determine whether a material is transparent from the energy levels and filling.

c) Be able to determine whether a material is metallic from the energy levels and filling.

Filling energy levels

1 million eV

Nothing in between!

5 eV

4 eV

1 eV

There are 3 electrons in this material. What is the lowest energy photon that it could absorb?

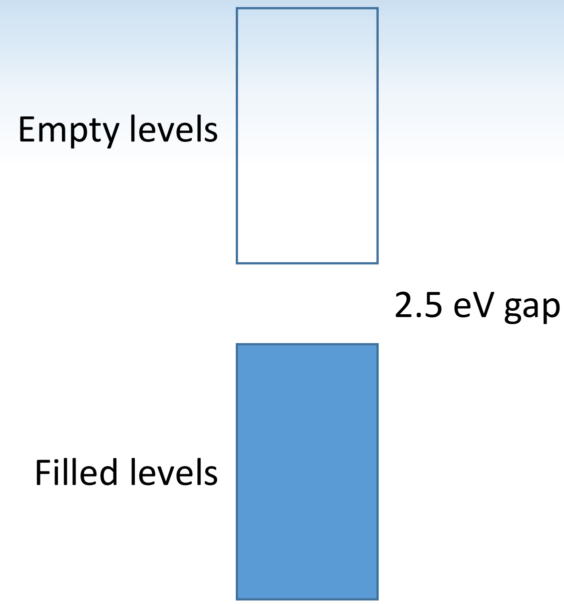
a) 1 eV
b) 2 eV
c) 3 eV
d) 4 eV
e) 5 eV

What is the energy of the second excited state?

a) 4 eV
b) 5 eV
c) 9 eV
d) 10 eV
e) 14 eV

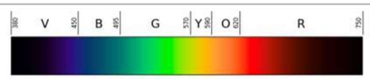
Unit 11: Energy levels

A material has energy levels as diagrammed.



What is true about the material?

a) It will conduct electricity very well.
b) Red light will pass through it.
c) Blue light will pass through it.



Color	Wavelength	Frequency	Photon energy
Violet	380–450 nm	680–790 THz	2.95–3.10 eV
Blue	450–485 nm	620–680 THz	2.64–2.75 eV
Cyan	485–500 nm	600–620 THz	2.48–2.52 eV
Green	500–565 nm	530–600 THz	2.25–2.34 eV
Yellow	565–590 nm	510–530 THz	2.10–2.17 eV
Orange	590–625 nm	480–510 THz	2.00–2.10 eV
Red	625–740 nm	405–480 THz	1.65–2.00 eV